Establishing Green *Design* Systems

Whole systems design analyzes every building system and integrates them so that the whole is greater than the sum of the parts.

- Bill Reed,
The Hillier Group, 1997

CONTENTS

Green Team Building & Goal Setting

Building a "Green Team" and setting project goals is one of the most fundamental steps in creating a high-performance green building, but is often overlooked in the scheduling and financial pressures of our competitive market. In order to benefit from the new opportunities that green building offers, all members of the project team must be educated and oriented to the goals, costs and benefits of high-performance green buildings. To be effective, the process must be horizontally and vertically integrated, and "trans-disciplinary". The building team needs to work together to define requirements and to identify synergistic opportunities. Knowledge specific to each system and sub-system must be shared to achieve high levels of integration and resultant higher levels of building performance.

" Partnership is the best way to pursue established project goals and criteria, following the whole-building integrated design approach; to establish and maintain communication among the team members; and to resolve issues related to design changes, problems with product availability and other issues quickly."

Sustainable Building Technical Manual, PTI, 1996.

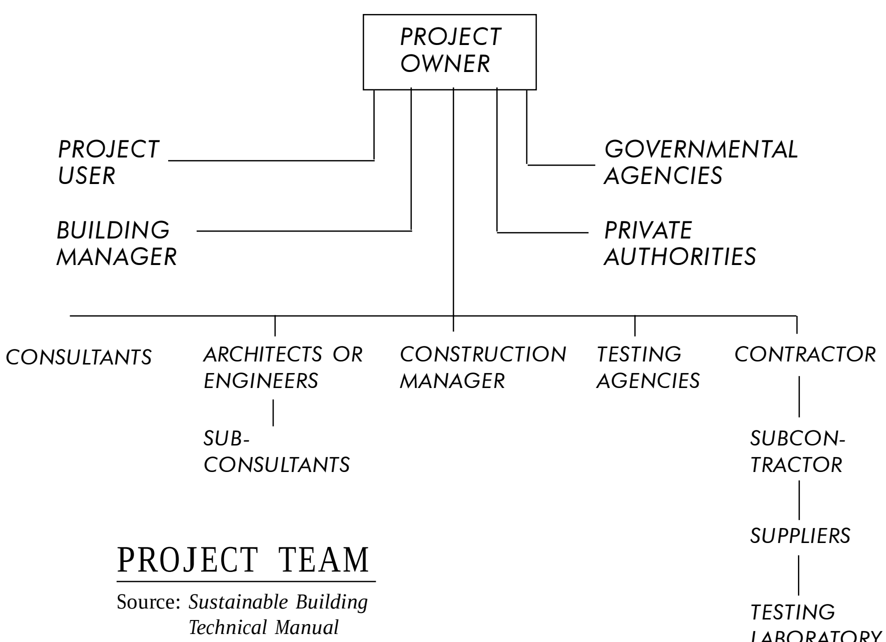
Creating a team to create a high-performance green building should be a gathering of representatives from all parties that have a stake or input into the building. In a conventional design process, the typical "team" of the client, the architect, engineers, consultants and contractors are often involved in a linear, "need-to-know" basis. Each party completes their tasks then passes it on to the next party.

In a high-performance green building design, the focus is shifted from a compartmentalized process to a multidisciplinary approach. Team members should be involved as the project's goals are being set to ensure that future decisions will be made with the project intentions intact. Early involvement also opens the communication paths for design integration and effective troubleshooting as the project develops. The team created for a high-performance green building may include the project owner, the project user, the building manager, architects, engineers, consultants, a construction manager, the contractor, subcontractors and suppliers, government agencies, the local community and even funding agencies. Nonprofits and universities can provide areas of expertise such as technical information and group facilitation.

In order to create a comprehensive and cost effective design, fee structures and consultant costs must be based on a different time allotment and compensation schedule. A typical high-performance design process is "front end loaded" and research intensive to create a building that goes up more quickly, easier and more economically. This may mean involving consultants earlier in the process, allowing extra time to review performance options through energy modeling and getting preliminary pricing for different options. Typical fees and scopes of work do not involve this level of depth early in the process. For example, the traditional scope of work for the design professional usually involves project management. In a high-performance green building, the design professional's scope can include typical project management tasks as well as facilitation of the project as a team leader. In this case, schedules and fees must allow for extra time to gather input from the team members and to integrate the information.

For the process to result in an integrated design, all parties must be educated in and committed to the high-performance goals that have been set for the project. This can be done through goal setting early in the process. The *Sustainable Building Technical Manual* recommends the following steps be taken to develop meaningful and achievable goals: develop a vision statement; develop goals to reflect the vision; define design criteria; and prioritize the design criteria.

First, develop a vision statement such as, "The owners want to minimize their impact on the environment." The second step is to develop goals that reflect the vision. The previous vision statement might include among its goals, "The owners want to save energy by using passive technologies and natural daylighting." Third, this goal must be developed into defined, achievable design criteria such as, "The ambient light levels will be lowered to 30 footcandles and will use skylights and T-5 fluorescent lights to reach that level." Finally, the team must prioritize the design criteria. For example, if the quality of natural daylighting is more important than super-efficient fixtures, decisions can be made easily if the budget only allows for one option.



PROJECT TEAM

Source: *Sustainable Building Technical Manual* PTI, 1996.

checklist

team building/goal setting
process

- *Scrutinize each project for its potential to be administered through a team approach.*
- *If a comprehensive team decision-making approach is not possible, involve as many interested stake holders as possible in the design process.*
- *If interested individuals or team members do not have the time or expertise to develop a team approach to the project, investigate whether it is available through local nonprofit organizations, universities, community design centers or professional design organizations.*
- *Commit to educating your colleagues and constituents to the benefits of team integrated design. Today, there is sufficient literature and references that examine all aspects of sustainable design and development.*
- *Evaluate all aspects of the project from the standpoint of environmental stewardship as economic opportunity.*
- *Consider the impact and ramifications of design decisions from upstream to downstream and over the life of the building.*
- *Make sure that all stakeholders, especially those who live in proximity with the project, are aware of the true costs of development, including long term impacts on the community and the life cycle aspects of the project.*
- *Use computer modeling and life cycle cost analysis tools whenever possible.*

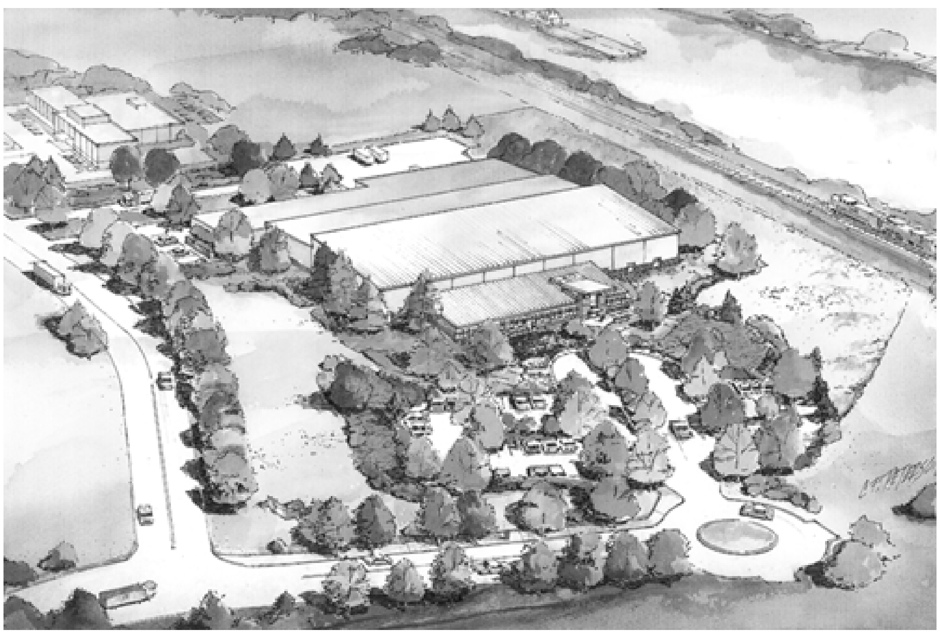
DESIGN systems

Site

Site quality is the interrelationship of regional, community, neighborhood and location-specific systems that collectively comprise the physical setting within which new construction or renovation occurs. High-performance green buildings optimize the positive attributes of these systems, seek to repair that which is damaged in each, and work to achieve the best possible balance between the programmatic needs of the project and the host site that supports it. The requirements of site systems are those that support the physical presence of the structure, address its demand for energy, allow for nutrient and resource flows through the facility to the site, and otherwise provide the balance of functional needs dependent on building type and programmatic issues.

The landscape design for the Greater Pittsburgh Community Food Bank distribution facility incorporates bioretention basins as well as native and edible plantings in an office/industrial park context.

Graphic: Gardner+Pope Architects



In many projects, early decisions on the siting of a building can have the greatest impact on building performance. Sustainable design recognizes the building's relationship to and impact on the larger context of community and region. It also strives to balance the opportunity for environmental stewardship, economic opportunity and the demands for services and resources that projects place on their surroundings. That balance is most likely achieved if the following considerations are included in the planning process:

High-performance green buildings recognize their context. The site is considered as part of a larger whole. The impact of the project on the regional energy supply networks, water supply and treatment, waste streams, traffic patterns and counts, existing civil infrastructure and other site-specific concerns is evaluated against life cycle cost criteria and environmental planning and design requirements. Site planning is done according to the surrounding context rather than by overlaying familiar patterns and solutions. By looking beyond the site boundaries, connections can be established and opportunities realized that would not be apparent in a narrow-focused approach.

Sustainable design and development strives to establish or maintain contiguous networks with other natural systems within and beyond the site boundaries. Site design should not fragment the landscape or destroy existing links that may weave through the site and the surrounding community. Project designers should familiarize themselves with the greater community of flora and fauna before addressing a limited site area to understand what important relationships exist. Good planning minimizes areas of vegetation disturbance, earth grading and water channel alteration.

High-performance green buildings support native habitat in developed landscapes and sites to maintain environmental quality essential to all resident plant and animal species. Sustainable site design recognizes the importance of native or natural habitat in urban settings as well. Much can be done in a small area to create a suitable habitat for a wide variety of urban dwelling birds and animals. Often these species can be quite useful in controlling unwanted pests and insects.

Sustainable site design promotes biodiversity. Good site planning strives to reestablish diverse natural habitats and organic patterns that reflect the living processes of the site. This be-

For more information see References and Resources:

- *Site & Landscape Design/ Water Conservation*
- *Land Use & Community Planning*

Reuse damaged sites to improve potential liabilities and to preserve relatively undisturbed areas.

Photo: Studio for Creative Inquiry

gins with an understanding of the dynamics of soil and the importance of nutrients and organisms that it supports. It is best to minimize monocultures such as large expanses of lawn unless necessary for building program functions. Ground covers and edible landscaping minimize maintenance, support animal and bird populations and improve the visual qualities of the site. These plants are preferred over labor, energy and chemical intensive landscape designs. Integrated pest management limits the use of herbicides or pesticides.

Use existing infrastructure. Designers should look for opportunities to repair sites damaged by inappropriate use or poor design. Restoring previously used sites, especially in urban areas, has multiple benefits for the existing urban fabric and the surrounding environment. The savings inherent in using the existing civil infrastructure, streets, transportation systems, lighting and building services can be significant. Greenfield development sites should be used only when other sites are unavailable or unsuitable for the project being considered. Greenfield development is usually symptomatic of sprawl and should be carefully weighed against long term environmental, economic and quality of life issues in the community.

Existing site amenities and buildings should be reused whenever possible to reduce the need for completely new construction or land consumption. Existing structures and site improvements represent a significant investment in energy, materials, services and our cultural heritage. The goals of urban and regional sustainability are completely in keeping with acts of preservation and adaptive reuse of damaged sites and existing structures. Recent case studies indicate that there is substantial marketing appeal and sound investment opportunities for those willing to explore these options.

Building orientation for passive heating, cooling and ventilation. Orient buildings to benefit from passive solar heating, daylighting, natural ventilation and water systems. A sustainable design process analyzes and evaluates the potential benefits from passive heating and cooling and natural ventilation. Energy modeling programs that use climatic data are critical when examining options.

Capitalize on daylighting. Analyze surrounding structures or site features that may shadow your building. Uncontrolled glare from adjacent structures or water features can negatively affect attempts at controlled daylighting.

Renewable energy production. Examine the site for the potential of renewable energy production. The advent of photovoltaic systems that create electricity from sunlight requires access to the sun's path. Many buildings will be retrofitted with this technology in the future as systems' performance increases and costs per kilowatt fall. Simple accommodations in roof structures and solar access can make both new and retrofitted application much easier and cost effective.

Several locations in the Commonwealth are being analyzed for wind power. The deregulation of the utility industry, as well as more efficient and cost effective wind generation technology, make wind power a viable energy source in some areas. Some locations, most notably the northwest and the central Appalachian regions of the state, show good potential for wind

The outdoor spaces at the CCI Center are oriented to the south and feature solar panels integrated as shade roofs.

Photo: Marc Mondor

Fountains can have cooling effects on the local microclimate.

Photo: Christine Mondor

Site cont.

energy applications.

High-performance green buildings "close the loop" by processing "waste" products on site to regain resources. Sustainable design promotes the idea that there is no such thing as waste, only resources out of place. The designer must analyze or model the energy, water, material and nutrient cycles in buildings prior to development to determine the best fit between the building and the site. Alternative waste treatment systems, especially in stand-alone subdivisions and rural settings, can significantly reduce the impact of development in rural areas.

The emergence of eco-industrial parks and corporate complexes that integrate sustainable landscaping and wetlands is testimony to the desirability and cost effectiveness of plant-based treatment systems. Large scale developments are being planned around living waste treatment facilities that are cost competitive with conventional civil infrastructure and, in many cases, more reliable.

> *" The people have a right to clean, pure water, and to the preservation of the natural, scenic, historic and aesthetic values of the environment.*
>
> *Pennsylvania's public natural resources are the common property of all the people, including generations to come. As trustees of these resources, the Commonwealth shall conserve and maintain them for the benefit of all the people."*

Article 1, Section 27 of the Pennsylvania Constitution

Use landscaping to your advantage. Plant vegetation to conserve energy. Programs such as the U.S. Environmental Protection Agency's *Cool Communities* indicate that significant cooling can be achieved in urban environments through effective tree planting and landscaping. Large scale developments that use landscaping for cooling are reaping the benefits of energy conservation, improved visual environments and increased property value.

Landscaping materials should be obtained from local sources whenever possible to minimize transporting them long distances. The most cost effective materials may be those which have the least maintenance requirements. Ideally, facilities which occupy landscaped lots should consider on-site composting of clipping, planting materials and other organic materials generated on site.

Make site features and amenities work for you. Excess fill or a sloping topography can be used as earth berming to save building energy. Water features can provide opportunities for evaporative cooling, regeneration of the building cooling system, irrigation and even fire suppression. Storm drainage and retention can be a celebrated feature as an ecologically diverse wildlife attraction. Storm drainage should incorporate, to the greatest extent possible, existing surface flows and waterways. Impervious surfaces and retention or detention basins that recharge ground water and serve as irrigation storage are preferred to traditional civil engineering solutions.

Outdoor spaces should be created to encourage connection to the environment. South facing outdoor spaces that are sheltered from wind and rain can become "season extenders," increasing the usefulness of the site.

Building services. Minimize the impact of the building on the site. This may include the reduction of scale, clustered facilities and siting the structures on blighted areas of the site.

checklist

Early in the planning process, utility systems must be developed that will work with established natural areas. When utility lines are necessary they should be buried near other corridor areas, pedestrian or vehicle ways that are already disturbed. Low pedestals or shielded conduit, visually buffered, is preferred to overhead services.

Separate conflicting uses. Mechanical system noise or odors from on-site waste disposal facilities must be properly considered. Building air intakes must avoid fumes and keep odors from entering the HVAC system.

Building acoustics can also be greatly improved by paying close attention to the context of the building. Avoid putting spaces that require controlled acoustic environments near elements such as highways, train tracks or even areas of human activity like playgrounds.

Site lighting. Creative site lighting can combine accent lighting used to highlight site and building features with the security necessary to safely use the site. Site lighting design should identify and prioritize areas that must be lit for safety or other reasons, what lighting is coming onto the site already and the areas or elements that would gain from accent lighting. Site lighting fixtures should be energy efficient and be designed to minimize wasteful "light pollution," or misdirected energy.

Lighting design can be greatly enhanced and made more efficient by using lighting design software, especially if it is performed by an experienced lighting designer. Designers are also aware of new technologies such as a growing number of outdoor fluorescent lamps, as well as solar powered charging systems and energy efficient controls.

Site Systems

- *Recognize context and the impact of a building beyond the site boundaries.*
- *Understand that landscapes are interdependent and interconnected.*
- *Promote biodiversity. Urban, suburban and rural areas all have native populations of plants and animals that should be supported.*
- *Reuse brownfields and other already disturbed areas. Developing new projects on pristine land, especially agricultural grade acreage should be avoided and always weighed against the consequences of abandoning existing buildings, sites, infrastructure and the resources and energy they represent.*
- *Evaluate site resources to ascertain how each can enhance the proposed project and visa versa. Work to maximum advantage of the site's solar and wind attributes.*
- *Locate buildings to minimize environmental impact. Buildings can be clustered to avoid disturbing large areas. Limit road construction and service corridors. Select previously used or developed sites if they are suitable and available.*
- *Landscape for energy conservation.*
- *Plan for growing food and returning energy and nutrients to the earth. Use edible landscaping that integrates site runoff, irrigation, composting and recycling of building waste.*
- *Recognize the value of existing buildings, streets and other site amenities. Reuse existing buildings and structures whenever possible, and extend adaptive reuse efforts to include damaged sites.*
- *Choose site materials and plantings that have low maintenance and water requirements.*
- *Use the Geographical Information System (GIS) to help assess and organize site information such as vegetation, hydrology and topography. Explore programs like "CITYgreen" that can model different site configurations for energy and resource efficiency.*
- *Implement a resource efficient lighting scheme.*
- *Optimize building shape and orientation to take advantage of sunlight, wind and natural features.*
- *Examine each site for the potential of renewable energy from solar, wind and geothermal sources.*
- *Orient a building to an east-west axis to decrease summer cooling bills as well as winter heating loads. Site amenities such as ponds or fountains can provide visually pleasing areas for evaporative cooling.*
- *Be aware of the regional wind direction, local wind patterns and the effect of winds directed by surrounding structures and vegetation. Site and configure your building to benefit from cool summer breezes while keeping out winter winds.*

DESIGN systems

The enclosure systems have a direct impact on the thermal and visual comfort of a building's occupants. Enclosure systems also have a major impact on energy usage. The enclosure systems must create thermal comfort by making appropriate responses to local microclimates. Enclosure systems also play a strong role in creating the indoor visual environment through daylighting and views.

Enclosure

CMU's Intelligent Workplace features operable exterior shading devices, operable windows and high-performance glass.

Photo: Bob Kobet

Thermal Comfort

The purpose of the enclosure system is to create a comfortable thermal environment. This is accomplished by regulating air temperature, radiant heat loss or gain, solar heat gain, relative humidity and air movement. There are many factors that should be considered when designing for thermal comfort.

Recognize climatic concerns of the region. In Pennsylvania, enclosure systems must recognize the wide temperature variations and precipitation typical of our four distinct seasons. A "rain screen" system incorporates an exterior finish material with a full drainage cavity ventilated to the exterior to keep out moisture. A pressure-equalized metal or glass curtainwall or a vented masonry cavity is preferred to single wythe masonry or unvented exterior insulation systems.

Acknowledge impact of the orientation on the building. The enclosure on each side of the building has to deal with different conditions based on its exposure to sun and wind. Southern facades must accommodate a large swing in temperatures from day to night. East and west facades must be suitable for shorter periods of sun exposure, but at angles that are more difficult to control. The northern face of an enclosure does not usually endure temperature extremes, but often must address the predominant winds of the region.

Within a single building, there may need to be multiple responses to enclosure based on the microclimate. For instance, the insulating R-values of a wall system might need to be increased or decreased depending on its location in the building. The west and south facades, which in some cases can experience temperature swings of 70 degrees or more, should be made of materials and detailed to allow for expansion and contraction, the migration of moisture and maintenance for harsh weathering conditions. The use of computer modeling can reveal the performance of each building enclosure element. This, in turn, enables the designer to optimize the building's performance.

Configure the envelope to deal with the conditions created by different orientations. Light shelves and exterior shading devices on the south face of a building can be used to increase light penetration and decrease thermal loading of the envelope. Light shelves can have many configurations, including a single shelf or multiple shelves. Some manufacturers have standardized sizes and configurations for ready application.

For more information see
References and Resources
• *General Sustainability*

Daylighting from overhead can create a dramatic area to work and meet people, such as at the Buchart Horn building.

Photo: Bob Kobet

The west and east sides of a building can also be configured with vertical fins, deep recesses or other articulation to decrease the impact of low sun angles on the building's thermal loading. Often, off-the-shelf elements can be configured to provide this benefit without custom products or systems. Finally, be aware of the R-value of the enclosure relative to the varying microclimates. Large expanses of wall or window with a low R-value can create uncomfortable radiant losses or gains for occupants.

Use the envelope enclosure to minimize conditioning loads. Many green buildings that provide daylighting and access to operable windows have greater perimeter areas and are "envelope-dominated loadings." It is especially important that envelope-dominated buildings be sited well, with their enclosure system "tuned" to the different microclimates and orientations. By using appropriate enclosure materials, external shading devices, reflective roof or wall colors and high-performance glazing, the envelope design can play a large role in minimizing space conditioning loads.

Additional savings can be achieved by allowing for passive conditioning and through the use of dynamic enclosures. Dynamic, or operable, enclosures can include things as familiar as operable windows to miniblinds to moveable exterior light shelves. Some systems are best controlled automatically, based on changes in the environment or on thermal loading. Other elements should be user controlled, an important step in creating occupant comfort.

Understand how the enclosure's materials work as a system. For this, it is important to know the basic physics that affect the enclosure -- temperature, moisture movement and air movement.

Temperature. Elements within a wall, roof or floor should be designed to include adequate insulation to ensure thermal comfort. This is especially important where the occupants will be close to or touching the envelope, such as at a wall or floor. Radiant and conductive heat losses caused by inadequate insulation can overwhelm even the best designed mechanical system. Avoid thermal bridging, or heat transferred across or through enclosure elements, by examining enclosure details and designing for thermal breaks.

Moisture movement. The effects of moisture migration are not often felt by occupants directly, but can greatly affect the longevity of an enclosure system and the entire building. Because warmer air can hold more moisture than colder air, there is a constant movement of water vapor between areas of different temperatures on the inside and outside of a wall system. In a poorly designed enclosure system, uncontrolled vapor can condense within the wall or roof and eventually cause deterioration. Enclosure systems must include a vapor barrier on the warm side of the enclosure (the interior side in Pennsylvania).

Exterior moisture migration from rain or capillary action can be a problem. Enclosure systems must provide for the removal of moisture that penetrates the exterior skin of a building. For example, brick cavity walls include a cavity for drainage and flashing and weep holes as a standard detail. All enclosure systems should be detailed with ways for water to exit the system harmlessly.

The Intelligent Workplace at Carnegie Mellon University has a dynamic thermal envelope with movable sunscreens, passive ridge vents and other technologies.

Photo: Bob Kobet

Enclosure cont.

The new DEP headquarters employs exterior and interior light shelves to bring light deeper into the space.

Photos: Bob Kobet

Air movement. Finally, elements within an enclosure system must be arranged to limit air infiltration and exfiltration. Without an effective air barrier, uncontrolled infiltration of warm or cool air can cause occupant discomfort through convective heat loss and gain. It also can carry water vapor into the enclosure system, where it can condense. Areas of solid material such as sheets of glass, sheathing, etc., are effective air barriers. Areas where materials make transitions or turn corners should be detailed carefully to avoid unwanted infiltration.

Visual Comfort

The enclosure can have a great impact on determining the visual quality of interior spaces. Visual comfort is provided by an environment with good views and appropriate light levels, free of glare and excessive contrast. The decisions made on the size, configuration and location of windows in the enclosure can decrease or increase the need for electric lighting and can provide better work environments for the occupants.

Consider the following when designing the enclosure:

Design buildings with a narrow footprint. Buildings with a shallow depth provide access to daylighting as well as opportunities for passive conditioning and views.

Provide views to the outside. Views to the exterior environment provide occupants with a sense of connection to the outside. Windows can improve morale by helping to create an awareness of the seasonal cycles, daylight, weather and outside activity. Studies performed by the Electric Power and Research Institute (EPRI) reveal that people are more comfortable and productive in environments that combine daylight with well-designed electric lighting systems.

Size and orient glazing area to allow for daylighting. Large amounts of glazing, especially on the east and west facades, are not an appropriate approach to daylighting, as they are difficult to shade. Occupants near to the window often complain of excessive contrast and glare, while others deeper inside the building do not derive much benefit. A split window configuration combined with a light shelf allows for light to penetrate deep into a space without creating problems for those next to the window. Windows that are located higher in a space or above a light shelf provide a better quality of light, while windows below can be controlled with blinds as conditions require.

Choose an appropriate performance for glazing for the different building conditions. The two factors that affect visual performance of glass are the shading coefficient and the visible light transmittance. The shading coefficient is determined by the amount of solar energy that comes through the window as infrared energy. Visible light

> *" When a series of linked efficiency technologies are implemented in concert with each other, in the right sequence and manner and proportions, there is a new economic benefit to be reaped from the whole that did not exist with the separate technological parts."*
>
> *Factor Four,* Weizsacker, Lovins and Lovins

transmittance describes the amount of daylight that penetrates the glass. The dark grey and reflective windows of the 1980s were an attempt to balance increasing internal loading of computers and lights against the sun's loads. These windows didn't allow as much heat gain, but they also didn't allow much light. In some installations, it is difficult to tell the weather or the time of day because of the strong grey cast.

Fortunately, advances in glazing and coatings have created more options. Now clear, green tinted and blue-green tinted glass provide similar shading coefficients with better visible light transmittance. Always look at shading coefficient and visible light transmission when choosing a glass. Consider "tuning" your glass to different orientations to compensate for various lighting conditions.

Allow occupants to adapt to changing conditions with window treatments. Even the most careful window and glazing design cannot account for the dynamics of changing lighting conditions. Excessive contrast and reflective glare can be dealt with by designing operable blinds and moveable shades with user controls.

Perforated shading devices also allow high levels of visibility to the exterior while providing thermal and UV solar protection.

checklist

Enclosure Systems

Thermal Comfort

- *Optimize the thermal envelope before relying on building space conditioning systems for environment control.*
- *Use available computer modeling whenever possible to investigate the performance of various thermal envelope materials and configurations.*
- *Understand the relationship between radiant surface temperatures and comfort. High performance glazing and enclosure systems that provide acceptable interior surface temperatures can reduce the need for expensive perimeter conditioning systems.*
- *Recognize the influence of site and building orientation when designing building enclosure systems. Select wall and glazing materials that respond to variations of wind and solar loads associated with orientation.*
- *Understand the role of building mass in controlling thermal comfort, especially in interiors. High mass buildings have an inherent ability to stabilize temperature swings and can contribute to cooling strategies using nighttime air.*
- *Bring the outdoor into the building. Designs that incorporate atriums, light wells or connections to patios and terraces can also integrate natural light and ventilation.*
- *Choose enclosure systems that perform well in varying seasonal conditions. Exterior rain screens with vented voids behind, such as brick cavity walls or pressurized curtain walls perform better that solid masonry or low quality window mullion and glazing combinations.*
- *Select enclosure materials and detail building assemblies to limit uncontrolled infiltration.*
- *Depend on thermal envelope performance and natural space conditioning and ventilation strategies before engaging mechanical systems*
- *If outside conditions are acceptable, design the structure to take advantage of prevailing breezes to maximize natural ventilation.*

Visual Comfort

- *Provide environments that are visually stimulating. Humans respond well to variations in lighting levels, comfortable contrasts and pleasant changes in light and shadow.*
- *Provide as much natural light as possible. Coordinate supplemental light sources with available daylight.*
- *Consider creative integration of daylight, energy efficient lighting options and effective control strategies. Include daylight as a factor when trying to meet industry standards for lighting.*
- *Optimize the spaces being illuminated with the appropriate colors, surface treatments, room proportions and ceiling heights for the tasks involved.*

DESIGN systems

Mechanical

Mechanical systems are an important component in creating thermal comfort and good indoor air quality. The design of mechanical systems should increase the occupants' thermal comfort, downsize and decrease equipment first costs, and lower long-term operation costs.

Mechanical systems must also address the occupants' fundamental need for clean, fresh air to be supplied at all times. Conventional construction often simply recirculates pollutants, such as mold spores, allergens, volatile organic compounds (VOCs) and toxic fumes. High performance green buildings seek to minimize pollutants at their source, as well as to clean and condition air that has already become polluted.

To perform at peak efficiency, high-performance buildings operate with energy management systems that monitor and control interior environments.

Photo: Steve Lee

Thermal Comfort

The design of mechanical systems is often thought of as the sizing and specifying of mechanical equipment that occurs after the building is designed. High-performance green buildings consider the design of mechanical systems as integral to the entire process. Planning for a mechanical system starts with the fundamental decisions made in the building organization and design, and continues to the selection and location of equipment.

For example, by designing buildings to take advantage of natural light, ventilation and passive solar heating and cooling, designers can achieve a reduction in building space conditioning loads. Amory Lovins calls this "tunneling through the cost barrier." At the heart of the concept are many actions a designer can take to decrease loads on the HVAC system that will ultimately allow for a downsized system and less first costs. Design for passive conditioning can also result in increased building occupant comfort and cost benefits associated with increased productivity. These two strategies -– reducing first costs for equipment while creating spaces that increase productivity and reduce operations and maintenance associated with energy efficient operations is at the heart of green building economics.

Consider where building functions are located. Use spaces that require less conditioning, such as storage areas or circulation areas, as buffer zones on the north side of the building. Avoid locating small enclosed spaces or spaces with high internal heat loads near south facing areas that will also have demands from solar gain. Open spaces allow for a more even mixing of air and help distribute loads. Even the location of building equipment can affect efficiency and ultimate comfort. By locating outdoor mechanical equipment such as compressors on the north side of a building, the efficiency and the lifespan of the unit are increased.

Incorporate thermal zoning. High performance buildings rely on close scrutiny of thermal loads imposed from the building exterior, the building interior systems and equipment, as well as loads from building occupancy. A thorough understanding of how and where these loads occur enables designers to specify equipment that can closely and effectively match the estimated load. Design strategies that use smaller zones can address building occupancy more efficiently. Comfort concerns such as space conditioning along building perimeters versus interior core areas are best addressed when they can be well-defined and separated.

For more information see
References and Resources
• *Indoor Environment*

Condition the building using low energy features, such as this ridge mounted fan, before using energy intensive processes such as mechanical cooling.

Photo: Steve Lee

Large expanses of interior space involving a variety of conditions can seldom be effectively conditioned with a central system or limited controls.

Create thermally diverse environments. Uneven loading conditions combined with the diverse comfort levels of individual temperature preferences and occupant activity levels and their clothing makes a strong case for "thermally diverse" environments. High performance green buildings design for thermal diversity with decentralized space conditioning and ventilation systems. They are more simply deployed, understandable to building occupants and maintenance personnel, and are usually more efficient than large central systems that provide uniform conditions. Thermally diverse environments create many opportunities for energy conservation and more stimulating interior conditions while still meeting the requirements for thermal comfort set by ASHRAE 62 and 55.

A thermally diverse environment allows for a range of comfort tolerances by accommodating different occupant demands. Usually, design conditions do not have to be maintained in all areas at all times. Providing thermal conditioning separate from ventilation can allow for greater options for systems design and can increase the quality of thermal conditioning.

Design systems that have controls for individual occupants. Creating small zones that can be controlled by an individual or small group of persons helps eliminate discomfort and distractions. Elements as simple as good visual access to the outdoors can greatly affect the building users' comfort and psychological health. Location of thermal delivery units (registers, radiant heaters, etc.) near the occupant puts less demand on the main space conditioning equipment. One example is the use of a raised floor system incorporating the supply air plenum with individually controlled floor air diffusers.

When individual control is integrated within a thermally diverse environment, it is critical that building occupants and maintenance personnel are informed and able to operate and understand the system safely and efficiently. Building commissioning and occupant education helps to ensure that the environment is properly maintained

The design of mechanical systems is a process that begins with the basic decisions made in the building design. It continues through to the final decisions of equipment choice and location and ends with the commissioning, education and maintenance of the building and equipment.

Indoor Air Quality

Indoor air quality (IAQ) has emerged as a central issue in building design and operation due to its relationship to occupant health and productivity, as well as to energy conservation, building materials and HVAC system design.

Poor IAQ has been linked to sick building syndrome (SBS) and the associated building related illness (BRI). Research into learning disabilities, attention deficit disorders, chronic fatigue, allergies and several other mental, emotional and physical disorders has cited interior air quality as a cause. Because of a steady increase in the number of IAQ cases being litigated and the amount of IAQ information being widely disseminated in the popular press, there is added urgency to integrate IAQ design to minimize risk and

Individual control of temperatures and organizational flexibility can be easily achieved with a raised floor system that includes both mechanical and electrical services.

Photo: Gardner+Pope Architects

Common cleaning chemicals can cause headaches and sickness.

Photo: Bob Kobet

Mechanical cont.

limit liability.

Conversely, a building designed for good indoor air quality has many benefits. Numerous professional studies indicate that good indoor air quality is essential for maximum productivity, safety, morale and general well-being.

Minimize or eliminate the impact of exterior sources of pollution. Engine exhaust, wood smoke, pollen, trash odors, industrial pollution and other contaminants must be kept out of the building. Consider source location relative to air intakes, doors, operable windows, etc. Be aware of prevailing winds and other environmental conditions that carry pollution.

Minimize or eliminate interior sources of air pollution. Interior source control involves selecting stable materials manufactured with environmentally benign or recycled materials that do not contain VOCs or other harmful contaminants. Special consideration must be given to elimination of construction adhesives, paints, stains, sealants and carpet systems including underlayments, pads and glue that off-gas.

Materials must also be scrutinized for their ability to act as a pollutant absorber or "sink." Porous materials such as carpet, fabrics and drywall, can absorb interior pollutants and release them over time once the original pollution event has passed.

Control sources of pollution that relate to the ongoing operation and maintenance of the building. Healthy cleaning procedures are now recognized as one of the best ways of preventing interior air quality problems. Routine application of cleaning products, floor wax and wax strippers, disinfectants, herbicides and pesticides, carpet shampoo and detergents often contribute to indoor pollution. Benign alternatives exist for these traditional toxic materials and practices.

Ventilate for pollution removal. Effective ventilation provides fresh air for the building occupants, and draws air into conditioning equipment to remove pollutants from circulation. Simply following code requirements does not ensure effective ventilation. An assessment of the existing conditions, spatial configurations, partition heights and placement, operable windows, passive ventilation and other built elements will help determine the effectiveness of ventilation systems.

Ventilation air must be provided where it is most needed. This area, also known as the occupied zone, is the part of the space between the floor and head height where people move around and work. The velocity of ventilation air should be low enough that no occupant experiences discomfort from being too hot or cold. Air movement should be sufficient to avoid feelings of "stuffiness" or psychological discomfort from a perceived lack of ventilation.

Flushing spaces with ventilating air can be part of an air cleansing process, but should not be relied upon as the first strategy for ensuring good in-

> *" The cooling load itself can be reduced several fold by combining superwindows, efficient lights and office equipment, and better architecture.*
>
> *At the same time, people become more comfortable and the whole building costs several percent less to construct…"*
>
> *Factor Four,* Weizsacker, Lovins and Lovins

terior air quality. Ventilation control systems should be capable of being set to provide pre and post-work ventilation flushing periods, adjustable day to day in response to variations in work schedules and pollutant loads. Manual controls should also be integrated to provide additional flexibility to deal with special ventilation needs imposed by cleaning, polluting activities or accidents.

Filters are an important part of any ventilation system. The periodic cleaning or replacement of a system's filters will ensure that the system can properly remove impurities.

Improving IAQ should be sought by means of, in order of decreasing importance: materials choices, source control, passive and active ventilation, and the use of appropriate cleaning products. Benefits of good IAQ will include increased health and productivity and reduced liability.

checklist

Mechanical Systems

Thermal Comfort

- *Minimize loads on mechanical systems by optimizing orientation and envelope design.*
- *Organize interior spaces and locate equipment to minimize loads.*
- *Analyze the thermal requirements of each space and choose the most appropriate mechanical system for each area.*
- *Allow for thermally diverse environments that accommodate a range of heating and cooling requirements.*
- *Give building occupants control over individual environments.*
- *Use a building energy management system to monitor and optimize system performance.*

Indoor Air Quality

- *Evaluate the site and surrounding area for potential sources of interior air pollution. Carefully consider the impact of traffic, transit drop offs, parking lots, dumpsters and other pollutants that can readily enter a building.*
- *Avoid materials and furnishings comprised of petrochemicals and volatile organic compounds to reduce harmful off gassing.*
- *Give special attention to ventilation requirements and system configuration and controls.*
- *Perform cleaning and maintenance with nontoxic cleaning products and procedures.*
- *Pesticides and herbicides should be used sparingly and only when necessary. Benign, natural methods and materials are preferred over poisons and toxic agents.*

DESIGN systems

Interior systems must address a number of important issues to create a comfortable and productive environment. First, functional and spatial issues must be examined at all levels -- from the arrangement of spaces to the ergonomics of an occupant's desk arrangement. Second, acoustic quality must be designed to provide privacy, clarity and freedom from distraction. Finally, the design of electric lighting systems should complement the daylighting design of a building to create appropriate light levels free of glare and excessive contrast.

Interiors

The use of a variety of sound attenuating materials and configurations is critical to the success of an open office environment.

Photo: Gardner+Pope Architects

Functional and Spatial Issues

The architectural profession has traditionally concerned itself with design for spatial performance, with all of its physiological, psychological, sociological and economic demands. This includes knowledge about the quantitative aspects of functional quality, such as the size of space needed to perform a task to the time it takes to walk from a person's desk to the printer. It also includes knowledge about the qualitative aspects of building occupancy that affect our perception of a space such as the scale of a space and the color and texture of materials. High performance green buildings consider these elements as part of comprehensive systems that address a multitude of concerns.

Understand the programmatic needs of the building users. Analyze the requirements for the size and volume of spaces and the adjacencies that need to be created among them. Understand how people work with each other and how they interface with their environment. Daylit private offices should be located in core spaces to maximize visual access to the environment for all employees. A layout that is efficient for a user in terms of proximity, adjacencies and travel distances is often efficient for building materials and resources.

Implement organizational concepts to help building occupants work most effectively. Many organizations function well with groups of work stations clustered around a common area, creating a collaborative "teaming" concept. Occupants should have easy access to mechanical, electrical and telecommunications system devices. Organizational flexibility is made easier with "plug and play" infrastructure systems that can be reconfigured without extensive rewiring or reconfiguration by a contractor. Employers should invest in employee education about these systems to get the maximum benefit.

Consider the need for public interaction and private space with the performance and psychological needs of the occupant. In commercial buildings, there is a trend away from small, compartmentalized spaces to larger, open areas with visual and spatial connections. This often blurs the line between public and private and can create psychological stress. The occupant's need for acoustic and visual privacy must be balanced against the ease of communication that can accompany an open layout. This is best accomplished by providing an acoustic oasis / private area or by careful acoustic treatment of surrounding surfaces and furniture selections.

For more information see
References and Resources
• *General Sustainability*

Common areas provide opportunities for occupant interaction

Photo: Carnegie Mellon CBPD

Provide opportunities for occupant interaction with their environment with adaptability and flexibility. An adaptable environment allows for building managers to physically reconfigure spaces to suit occupants' needs quickly and inexpensively. A raised floor plenum allows all necessary systems to be easily reconfigured. This increases the ability of the occupants to adapt the space to meet organizational needs. It also saves money and resources by reducing materials and time needed to make the change.

A flexible environment is designed so that many different activities can occur in a given area. For example, a seldom used conference area might also become an often used lunchroom. Understanding when and how spaces are used can eliminate redundant spaces and save money on construction, operation and maintenance.

Create spaces, arrangements and elements to be anthropometrically and ergonomically comfortable. Desks, chairs and other equipment should be well suited to the physical needs of the user. This can be very important when someone is doing a repetitive task and the chance for injury is greater than normal.

Consider the effect a space or material has on the occupant's senses. A high-performance green building gives priority to the quality requirements of a building's spaces, such as a need for natural light or the calming effects that a color may have. Close attention to material selection and placement can make a user more aware of the pleasant qualities of their environment and contribute to good psychological health.

Acoustic Quality

As a means of interpreting our environment, our ability to hear is second only to our sense of sight. The acoustic quality of a space should enable the occupants to effectively perform their tasks. This includes suitable levels of speech privacy and intelligibility, freedom from distraction, the ability to concentrate and the safe operation of equipment. Good acoustic design often requires the involvement of an acoustic or sound engineer.

A structure which is well insulated and effectively air sealed to be energy efficient is an acoustically superior building. The same qualities are present in structures where mass is strategically placed to assist in storing passive solar gain. Light shelves and shading devices used to control daylighting can also limit sound reflected into buildings.

Sound from the sky vault is minimized by using high-mass roofs to reflect sound or strategically placed roof insulation to absorb noise from overhead. Atrium buildings and buildings set on podiums are examples of structures that can reduce ground-reflected sound transmission. Orienting light-mass building surface treatments and primary entrances away from traffic and other exterior noise sources will minimize intrusion into building interiors.

Replace the amount of impervious hard surfaces around a structure with soft surfaces and landscaping. This practice reduces the possibility of airborne sound from the sky vault bouncing toward the exterior surfaces of the building.

Indirect lighting supplements the daylighting from windows and skylights in the Intelligent Workplace.

Photo: Steve Lee

Interiors
cont.

Workstations that are designed to be flexible should be configured so that each occupant has adequate access to natural light and fresh air.

Photo: Bob Kobet

Lessen the impact of noise from exterior by reducing noise at the source and creating a sound resistant building envelope. Avoid orienting walls perpendicular to noise sources. Configure buildings to reflect sound instead of collecting it. Sound-reflecting glass and curtainwall assemblies are necessary when massive wall construction is not possible. Heavy walls and double-layer construction form a superior sound barrier, especially for low-frequency sounds, compared to light mass walls not specifically constructed for sound control. Detail construction and seal walls so that direct transmission paths are minimized. Do not align switches, outlets or supply and return registers to form direct paths from one side of a wall or duct system to another.

Design for interior sound transmission. Controlling interior sound transmission relies on good programming and spatial allocation, quality construction, strategic placement of acoustic treatment and construction detailing that recognizes how sound travels inside buildings. In high-performance green buildings, spaces with sound generating activities are located away from those requiring quiet. Buffer zones can be located to further isolate undesirable sound from spaces that require low sound levels. Most mechanical and HVAC equipment has acoustic design implications. Smaller equipment distributed throughout the building, may be more quiet and more easily controlled acoustically.

> "One fifth, of all electricity used in the U.S. goes directly into lighting-- actually, one quarter, when we add the energy used to take away the heat of the lights."
>
> *Factor Four,* Weizsacker, Lovins and Lovins

Lighting Systems

In high-performance green buildings, particular attention is paid to lighting systems due to the role lighting plays in our physical and psychological well being. In addition, lighting levels are directly related to internal heat gain and space conditioning loads.

There are several powerful lighting analysis software programs designed to be compatible with most computer aided design (CAD) systems. These programs enable the evaluation of combined daylight and electric lighting systems.

The four lighting factors that most affect visual quality are: illuminance (lighting levels and distribution), luminance ratios (brightness, contrast, glare), color rendition and occupancy factors. Optimal levels should be sought for each of the following.

The illuminance in a space is created by the interplay of artificial light and daylight. Design for acceptable illuminance depends mostly on the location of the light fixtures, the design of the reflectors and diffusers surrounding the lamp in the light fixture, and the design of the geometry and surface reflectances defining the space being illuminated by the light fixture. Controls are a critical component in effective daylight/electric light designs.

The second critical factor for visual performance is contrast ratio or brightness difference. This is the eye's ability to respond to ratios of two brightness levels. The human eye can clearly perceive only with a contrast ratio of at least 2 to 1, and cannot adapt with a contrast ratio greater than 40 to 1. Excessive contrast occurs when the luminance or brightness ratios are too high, resulting in discomfort or disability glare. Design for appropriate brightness contrast depends on the location of the light source, the shielding of the lamps (or of sunlight, in the case of daylighting) and the selection of appropriate work surface and wall surface reflections.

The third factor for visual performance is color rendition. A color rendering index (CRI) measures how well a light source renders color. While fixture location and configuration are important for illuminance design and ensuring appropriate contrast ratios, lamp type becomes critical for color rendition. A CRI of 100 indicates perfect color match, and a CRI of 50 means very poor color rendition. Only a few lamps can provide color rendering indexes over 85. While lighting design often dictates different color indexes for various tasks, approximating daylight is usually the best design practice.

Fourth, evaluate the human factors such as age, visual acuity and functional factors, such as the tasks to be performed. Given the range of occupancy, functional requirements and unknowns resulting from interior space modification, lighting controls are necessary for meeting this performance mandate. Controls are needed to manage both daylight and the artificial lighting fixture. Controls can vary from manual on/off switches to automatic continuous dimming of general overhead lighting and task lighting.

Given changing functions, layouts, climatic conditions and the availability of natural light, the flexibility of the integrated system enabling visual performance is most often determined by lighting controls. Yet, there is a great deal to be said for the sensitive designer who provides a varied and stimulating lighting environment.

checklist

Interior Systems

Functional & Spatial Issues

- *Plan space based on its use. Minimize areas dedicated to circulation.*
- *Allow for occupants to control and interact with their personal environments.*
- *Eliminate unnecessary redundancies. Design for shared services.*
- *Use human ergonomics as a major space design determinant and furniture and equipment selection criterion.*
- *Connect occupants to the natural environment whenever possible via operable windows, daylight, fresh air, etc. Make sure the strategies can be accommodated with the HVAC design.*
- *Provide recycling centers and other building amenities that enable environmental stewardship.*

Acoustic Quality

- *Evaluate the site and surrounding area for sources of noise pollution and undesirable sounds.*
- *Configure building massing, forms and building group relationships to reflect and dissipate sound.*
- *Use entrance air locks or revolving doors to reduce sound transmission and save energy.*
- *Make acceptable acoustic performance a primary consideration in the design of mechanical equipment and energy distribution systems.*
- *Evaluate open office environments and work spaces for acoustic performance. Scrutinize all surfaces, furniture and equipment for their role or impact on acoustic performance.*

Lighting Systems

- *Incorporate high efficiency fixtures, lamps and controls. Strive to reduce watts-per-square-foot design targets and actual connected loads.*
- *Enable occupant control of individual work stations or small work areas with task-ambient lighting systems, as opposed to large, uniformly lit interior areas.*
- *Include lighting systems in regular maintenance procedures to ensure optimum light output and energy efficiency.*
- *Begin with an effective daylighting scheme that optimizes the use of natural light.*
- *Design controls to balance available daylight with the secondary need for electric light.*
- *Create environments that are visually interesting or stimulating by integrating overall illumination, ambient and task lighting.*
- *Design lighting to serve the needs of building occupants. Uniform lighting seldom serves well as both ambient and task lighting.*

DESIGN systems

In high-performance green buildings, materials are evaluated comprehensively. In conventional construction, building projects are typically evaluated only on first cost. High-performance buildings consider all life-cycle costs. Benefits can also be derived from reusing construction materials and utilizing environmentally friendly materials. Overall, this leads to a high quality design that accounts for the environmental costs associated with creating, procuring and assembling materials, as well as their impact on building occupants when the structure is completed.

Materials

The new addition to the CCI Center was detailed with reclaimed brick and other used material.

Photo: Marc Mondor

Selecting materials for high-performance green buildings requires a balanced consideration of many factors. Project decision makers must weigh the long term performance and service of a material against such factors as first cost and environmental impact. Aesthetic appeal, maintenance and interior air quality concerns are also directly related to material selection. The project team must consider the environmental consequences associated with the acquisition, transportation and manufacturing of materials prior to construction.

It is important to look at material selection in a comprehensive manner at the beginning of a project. The following issues must be evaluated when choosing materials and building components for high-performance green building.

Integrate materials with building systems. High-performance green building design requires that materials, finishes and systems be considered as part of the overall integrated design. For example, the role of mass in building thermal and energy performance is well understood and may be modeled and predicted with available software. The strategic placement of massive materials within the building, therefore, has building space conditioning system performance implications and has attendant value as part of that system. The effectiveness of daylighting schemes is dependent on surface finishes and color selections in the spaces served by the daylight. Replacing a poor quality carpet in a space with an alternative surface treatment may eliminate a source of dust and volatile organic compounds while making the space healthier and more productive.

Choose products with the least toxic manufacturing process. The project team need to know how materials are obtained and manufactured to evaluate whether they are an environmentally responsible choice.

Specific products must be carefully scrutinized. For example, different types of rigid insulation use different foaming agents. Those that do not use chlorofluorocarbons (CFCs) or hydrochlorofluorocarbons (HCFCs) are the better choice. Similarly, carpets that are solution-dyed create fewer toxic byproducts. An electrostatic spraying process achieves a high quality, durable finish while allowing efficient reuse of oversprayed paint. Manufacturers that use preconsumer waste from their own processes have lower waste disposal costs and require fewer raw materials.

For more information see "References and Resources:"
- *"Building Materials"*

Materials such as lumber made out of recycled plastic is both attractive and durable.

At the same time, decision makers should be wary of references to non-toxic or "natural" materials. Arsenic, asbestos and lead are found "naturally" in the environment. Natural materials must also be considered in reference to the same standards of performance, durability and serviceability as non-natural materials.

Choose products that are manufactured with the least energy intensive processes. The amount of energy used to extract raw materials and process them into a product is called the embodied energy of a material or product. Generally, materials that depend on extraction-based industries such as strip mining or clear cutting are not as desirable as those that are remanufactured using less environmentally damaging processes. Materials that are not highly processed or dependent on synthetics are preferable to those that rely on energy and resource intensive processes.

Specify sustainable products, preferably with recycled content. Recycled content can be pre-consumer using material gathered from the manufacturing process, or post-consumer materials gathered from general recycling efforts. Many manufacturers now list the percentage of recycled content in their products. In Pennsylvania, the Pennsylvania Resources Council is a great resource for information on products manufactured with recycled materials.

As with all materials, the inclusion of recycled content does not guarantee a sustainable product. Avoid specifying materials that can only be downcycled at the end of their useful life. For example, composite wood products, laminated trusses, structural insulated panels (SIPs), cellulose insulation and many other products with recycled content have become mainstream. Specifying such materials can be done for reasons beyond the environment.

Consider reused building materials. When buildings are deconstructed rather that demolished, there are many materials that can be directly reused. The opportunity to reuse salvaged materials found on site begins with an assessment of what can reasonably be extracted from the building to be deconstructed. Inferior or overly damaged products often should not be reused for safety or other reasons. Code issues regarding lead, asbestos and other hazardous materials will prevent other materials from being reused.

In some areas of the country, there are organizations that specialize in selling used building materials (UBMs). In Pittsburgh, "Construction Junction" (sponsored by the Pennsylvania Resources Council) has set up an outlet to accept donations of UBMs and to find end-users. Often salvaged building materials are advertised in newspapers and community newsletters. Consider using these outlets to avoid sending materials to landfill sites.

Investigate how a product is packaged and shipped. The ability to minimize a waste stream at the source is the best way to create an effective recycling program. Specifying products with minimal packaging, buying in bulk, and offsite prefabrication are all ways the waste stream can be reduced. A growing number of manufacturers are willing to accept returned packaging

Some carpet manufacturers offer to "lease" their products and to reclaim and recycle them when their useful life is over.

Photo: Interface Inc.

Materials
cont.

The useful life of materials can be extended with creative reuse like the concrete in this patio.

Photo: Christine Mondor

material after delivery is made. Others have chosen to use recycled and/or biodegradable packaging. Avoid the accumulation of unused materials on a construction site and during operation and maintenance to reduce disposal costs.

Integrate material leasing options. Some companies have found ways to "buy back" their products when they have served their useful life. The products are then rehabilitated and reprocessed into a product for another segment of the market. For example, some carpet manufacturers offer leasing of their products, with the knowledge that 20 percent of the carpeted area will show 80 percent of the wear. Only the worn carpet is replaced to match the remaining carpet, while the removed carpet is recycled.

Use materials that will contribute to good indoor air quality. Avoid products with toxic, carcinogenic, or otherwise harmful content. Materials that offgas quickly and then stabilize are preferred to those that continue to emit harmful vapors.

If an offgassing material is unavoidable, allow for a period of offgassing to occur, preferably offsite, before the material is installed. If this is not possible, let the material offgas completely before the building is to be occupied. Finally, if neither of these options is possible, consider encapsulating a material with hypoallergenic sealants to limit offgassing. Coordinate all material air quality concerns with the building commissioning process.

Choose materials that do not require harmful cleaning and maintenance needs. For example, some types of floors may not emit harmful fumes when installed, but may require frequent stripping and refinishing.

Detail assemblies of materials for easy disassembly. High-performance buildings are designed with consideration of the service life of the building and the maintenance and disposal costs of the building materials should the structure be disassembled. Many high-performance green buildings use pre-manufactured modular structural and building enclosure systems that enable efficient assembly and disassembly. This helps them adapt quickly and easily to changing program requirements or updated technologies.

Detail fasteners and connectors to allow for replacement and eventual reclamation of materials. Avoid assemblies that cannot be reclaimed or combinations of materials that cannot be separated for reuse. Beware of the maintenance needs of different materials in an assembly. Allow for easy access to those materials that have frequent maintenance or replacement requirements.

Implement life cycle cost analysis to help make decisions. The economics of high-performance green buildings are based on life cycle cost analyses. Often more expensive first cost materials and systems can be jus-

"We are optimistic that our manufacturing processes and consumer preferences can and will change in the next century, leaving significantly less waste to handle. Until that time though, we must have management programs that reuse, recycle and reduce waste."

Final Report of the Pennsylvania 21st Century Environment Commission tified when evaluated against the in-place service life, thermal performance or reduced maintenance costs associated with better quality materials. First cost investment decisions regarding materials often accrue over the building's life in several ways.

A durable building material can cost more to purchase and install than a low first cost alternative, but will often pay for itself over time. A low first cost may hide the costs of repairs and eventual demolition, repurchase and reinstallation. This can be both expensive and inconvenient. In addition, there may be a long period of blight between the first signs of material wear and its ultimate replacement. More durable materials may be more pleasing to see and touch over the life of the building.

checklist

Building Materials

- *Reuse existing buildings, materials and infrastructure to reduce the amount of new materials required.*
- *Take life cycle costing into account, rather than first cost. This will typically lead to higher quality design and materials.*
- *Recycle construction waste at the job site. New markets are continually being developed for these materials.*
- *Minimize waste by designing for standard sizes. Avoid over design of building systems.*
- *Use value-engineered products such as prefabricated components for more efficient structures.*
- *Select durable and heavy materials that can provide thermal mass in buildings.*
- *Avoid materials that harm the environment. Specify local timber and wood products that are sustainably harvested if available, or use recycled plastic lumber or other alternatives.*
- *Do not specify equipment or materials that use ozone depleting chemicals.*
- *Choose materials with the lowest possible embodied energy that will accomplish the task. Lumber, brick, cement and glass contain relatively little embodied energy, considering their useful service life, compared to virgin plastics and raw aluminum.*
- *Specify as many locally manufactured materials and products as possible to support the local economy and minimize transportation.*
- *Build with salvaged materials whenever available. Older fixtures, moldings, and architectural artifacts are often of high quality and have unique aesthetic appeal. However, do not reuse plumbing and mechanical equipment that does not meet or exceed code requirements for safety, energy and resource efficiency.*
- *Carefully recycle chlorofluorocarbons (CFCs) when disposing of mechanical equipment and foam insulation containers.*
- *Minimize and recycle packaging materials.*
- *Develop and implement a construction waste management plan.*
- *Use materials that do not require frequent or harmful maintenance procedures.*
- *Determine what parts of a building may be eventually dismantled and detail their use accordingly.*